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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 574

PRESSURE DISTRIBUTION OVER AN AIRFOIL SECTION WITH A FLAP AND TAB

By CARL J. WENZINGER

1936

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s^2 or 32.1740 ft./sec.^{2}

m, Mass $=\frac{W}{g}$

I, Moment of inertia $=mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu.ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o}=\frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s. the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of *c.p.* from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_o, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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By CARL J. WENZINGER
Langley Memorial Aeronautical Laboratory

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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REPORT No. 574

PRESSURE DISTRIBUTION OVER AN AIRFOIL SECTION WITH A FLAP AND TAB

By Carl J. Wenzinger

SUMMARY

Pressure-distribution tests of a Clark Y airfoil with a flap and an inset tab were made in the N. A. C. A. 7- by 10-foot wind tunnel. The pressures were measured on both the upper and lower surfaces at one chord section. Calculations were made of the normal-force and pitching-moment coefficients of the airfoil section with flap and tab, the normal-force and hinge-moment coefficients of the flap section with tab, and the normal-force and hinge-moment coefficients of the tab section alone. In addition, comparisons were made of the theoretical and experimental values for an airfoil with a multiply hinged flap system.

It was found that peak values of the increments of resultant pressures due to flap or to tab deflection occurred at the flap and tab hinges, respectively. Also, the variations of increments of airfoil section normal-force and pitching-moment coefficients and of flap normal-force and hinge-moment coefficients, due to flap deflection with a given tab setting, were practically independent of the tab deflection. In addition, the variation of increments of tab normal-force and hinge-moment coefficients with tab deflection for a given flap setting was practically independent of flap deflection. Comparisons of the theoretical with the experimental forces and moments for the airfoil section with flap and tab show that the theory agrees fairly well with experiment for small flap deflections with the tab neutral, but that the theory indicates much greater effects than are actually obtained when the flap and tab are simultaneously deflected.

INTRODUCTION

A considerable number of airplanes are fitted with a small flap on one or more of the movable control surfaces. Such an auxiliary flap is ordinarily referred to as a "tab" and is usually set into the trailing edge of the control surface. When the tab is used to reduce the hinge moments of a control surface, it is known as a "balancing tab"; when used to trim the airplane in place of an adjustable stabilizer or fin, it is referred to as a "trimming tab."

The chief aerodynamic characteristics of tabs are covered in reference 1, which describes an investigation of a wing with serveral arrangements of ailerons and tabs, alone and in conjunction with other types of balancing arrangements. In reference 1 data are also included from tests of a tail surface of average proportions with several different tabs.

Because of the rapidly increasing use of tabs, particularly on tail surfaces where they replace the adjustable fin and stabilizer, there is a demand for information that can be used for stress-analysis purposes. In this connection, the designer desires to know the magnitude and distribution of the air forces acting on the various surfaces and the moments about the hinge axes so that the structure, supports, and control mechanism can be designed for maximum efficiency. The present investigation was therefore undertaken to make available information that would be of immediate use in the foregoing design problems.

The tests consisted of pressure-distribution measurements over one chord section of an airfoil with a flap and a tab. From the data obtained, calculations were made of normal-force and pitching-moment coefficients for the airfoil section with flap and tab; both normal-force and hinge-moment coefficients were computed for the flap section with tab and for the tab section alone.

APPARATUS AND TESTS

The N. A. C. A. 7- by 10-foot wind tunnel, in which the tests were made, is described in reference 2. A half-span Clark Y airfoil (fig. 1) that had originally been built for pressure-distribution tests of high-lift devices was used. The model was altered by installing at the tip a flap having a chord 30 percent of the airfoil chord and a span 40 percent of the half-span model. An inset tab was mounted at the trailing edge of the flap, the tab size and location being selected as representative of the average. The tab chord was 20 percent of the flap chord and its span was 50 percent of the flap span. The gaps between the flap and the airfoil and those between the tab and the flap were sealed with plasticine for all tests.

The airfoil, flap, and tab were all constructed of laminated mahogany to within ± 0.010 inch of the specified ordinates. A row of small orifices was installed in the upper and lower surfaces at one chord section located at the center of the span of the flap and tab. (See fig. 1.) This location was 20 percent of the semispan of the model inboard of the rectangular tip so that satisfactory section characteristics could be obtained which

would be outside the influence of the usually high local tip pressures. The half-span model was set up in conjunction with a reflection plane at its inboard end, the plane extending from top to bottom of the air stream and some distance ahead of and behind the model. A multiple-tube alcohol manometer photographically recorded the pressures on the airfoil section.

Pressures were measured for flap settings of 0°, ±15°, and ±30° with the tab neutral. With the flap neutral, pressures were measured for tab settings of ±10°, ±20°, and ±30°. The pressures were then measured for various combinations of flap up with tab down and of flap down with tab up. The angles of attack used in the tests (−5°, 0°, 10°, and 15°) covered approximately the range from zero lift to maximum lift.

Angles of attack and flap deflections were measured with respect to the airfoil chord; tab deflections were measured with respect to the flap chord. Positive flap or tab angles indicate a downward deflection with respect to the airfoil or flap chord. The tests were made at a dynamic pressure of 16.37 pounds per square foot, corresponding to an air speed of 80 miles per hour under standard sea-level conditions. The average Reynolds Number was 1,220,000, based on the airfoil chord of 20 inches as the characteristic length.

RESULTS

The results of the investigation, in their original form, consisted of pressure diagrams for the section as tested at different angles of attack and for different tab and flap deflections. In order to facilitate the interpretation and application of these results, the pressure diagrams are presented in the form of "increment" diagrams, which represent the changes in pressure distribution due to changes in the significant variables. The pressure diagrams for the basic section (i. e., neutral tab and flap) are also given so that the resultant diagram for any case may be obtained by addition of the increment and the basic-section diagrams. The principal advantage of the increment diagrams is that they may, by the principle of superposition, be applied to pressure diagrams for any other basic airfoil section, including the symmetrical section, that does not depart too greatly from the Clark Y section on which the tests were made. The diagrams of resultant-pressure distribution for the basic airfoil section are given in figure 2. The increments of resultant pressure for various tab and flap deflections are presented in figures 3 to 6. The figures give the results for a low-angle-of-attack condition, $\alpha=0°$, and for a high-angle-of-attack condition, $\alpha=15°$.

The important characteristics of the section as a whole and of the tab and flap, as functions of tab and

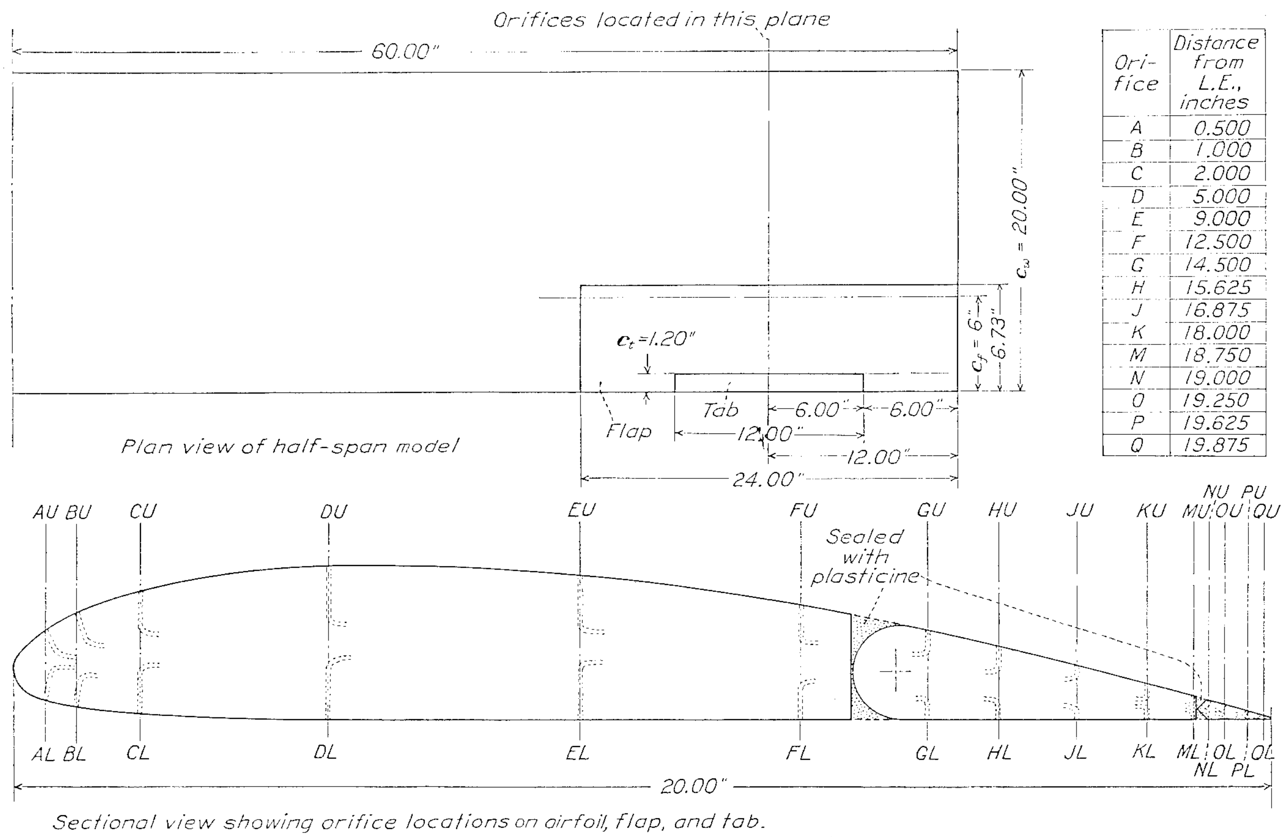

FIGURE 1.—Clark Y airfoil with tab and flap arranged for pressure-distribution tests.

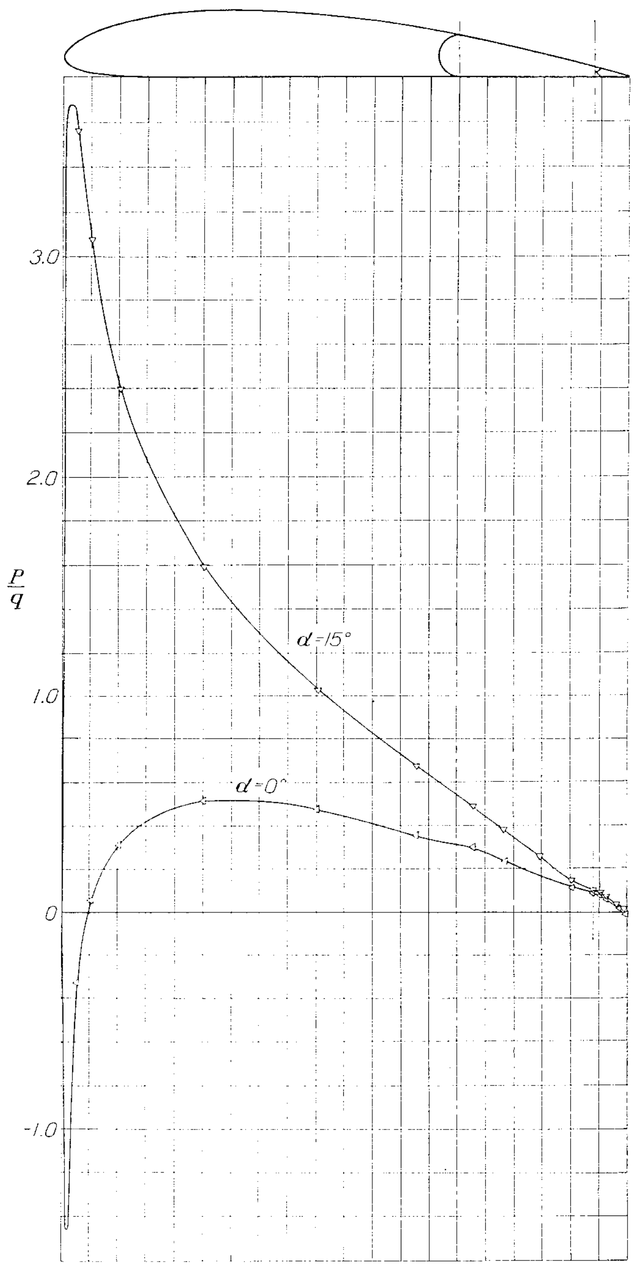

FIGURE 2.—Distribution of resultant pressure on airfoil section with flap and tab neutral. $\alpha=0°$ and 15°.

flap deflection, are also plotted as increments. These increments were obtained by deducting the basic-section characteristics from those for the section with deflected flaps, the characteristics being determined in each case by integration of the original pressure diagrams. Calculations were made of the following quantities in which lower-case letters are used to indicate section coefficients:

Airfoil section normal-force coefficient, $c_{n_w}=\frac{n_w}{qc_w}$

Airfoil section pitching-moment coefficient, $c_{m_{c/4}}=\frac{m_w}{qc_w^2}$

Flap section normal-force coefficient, $c_{n_f}=\frac{n_f}{qc_f}$

Flap section hinge-moment coefficient, $c_{h_f}=\frac{h_f}{qc_f^2}$

Tab section normal-force coefficient, $c_{n_t}=\frac{n_t}{qc_t}$

Tab section hinge-moment coefficient, $c_{h_t}=\frac{h_t}{qc_t^2}$

in which

n_w is the resultant pressure force normal to the airfoil chord.

m_w, the corresponding pitching moment about the quarter-chord point.

n_f, the resultant pressure force normal to the flap chord.

h_f, the corresponding moment about the flap hinge.

n_t, the resultant pressure force normal to the tab chord.

h_t, the corresponding moment about the tab hinge.

The subscript w refers to the airfoil section with flap and tab; the subscript f to the flap section with tab; the subscript t to the tab section alone.

The integrated coefficients for the basic airfoil section are plotted in figure 7 against angle of attack. Curves giving the increments for various tab and flap deflections are presented in figures 8, 9, and 10.

Figures 11 and 12 are plots of theoretical parameters taken from reference 3 and modified so as to apply directly to N. A. C. A. absolute coefficients. Comparisons of theoretical with experimental values of the forces and moments for the Clark Y airfoil tested with several different deflections of the tab and flap are shown in figures 13, 14, and 15.

DISCUSSION

Pressure distribution.—The effects on the distribution of resultant-pressure increments due to tab or flap deflection are shown by figures 3 and 4. Deflections of the tab or of the flap produce peak values of the pressure increments at the tab hinge or at the flap hinge, respectively. If the tab and flap are deflected simultaneously (tab deflection opposite to that of flap), then peak values of the pressure increments occur at both hinge axes but the resultant pressures act in opposite directions. (See figs. 5 and 6.)

Section characteristics.—The characteristics of the basic airfoil section given in figure 7 (tab and flap neutral) exhibit no unusual tendencies. For a given setting of the tab, the flap and tab may be considered as a flap unit. Then the effect of deflection of such a unit will be similar to that for an ordinary flap (e. g., aileron, elevator, or rudder). Increments to the basic values of airfoil section normal-force and pitching-moment coefficients are given in figure 8 for various flap

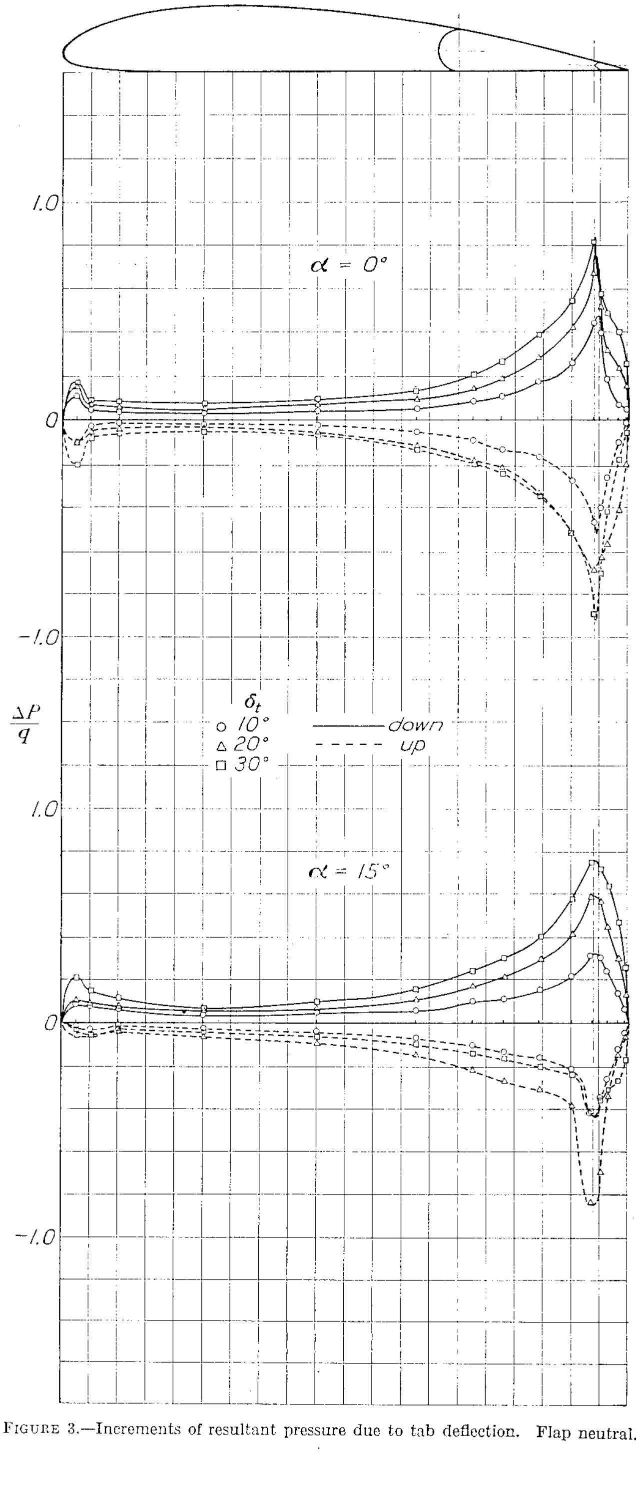

FIGURE 3.—Increments of resultant pressure due to tab deflection. Flap neutral.

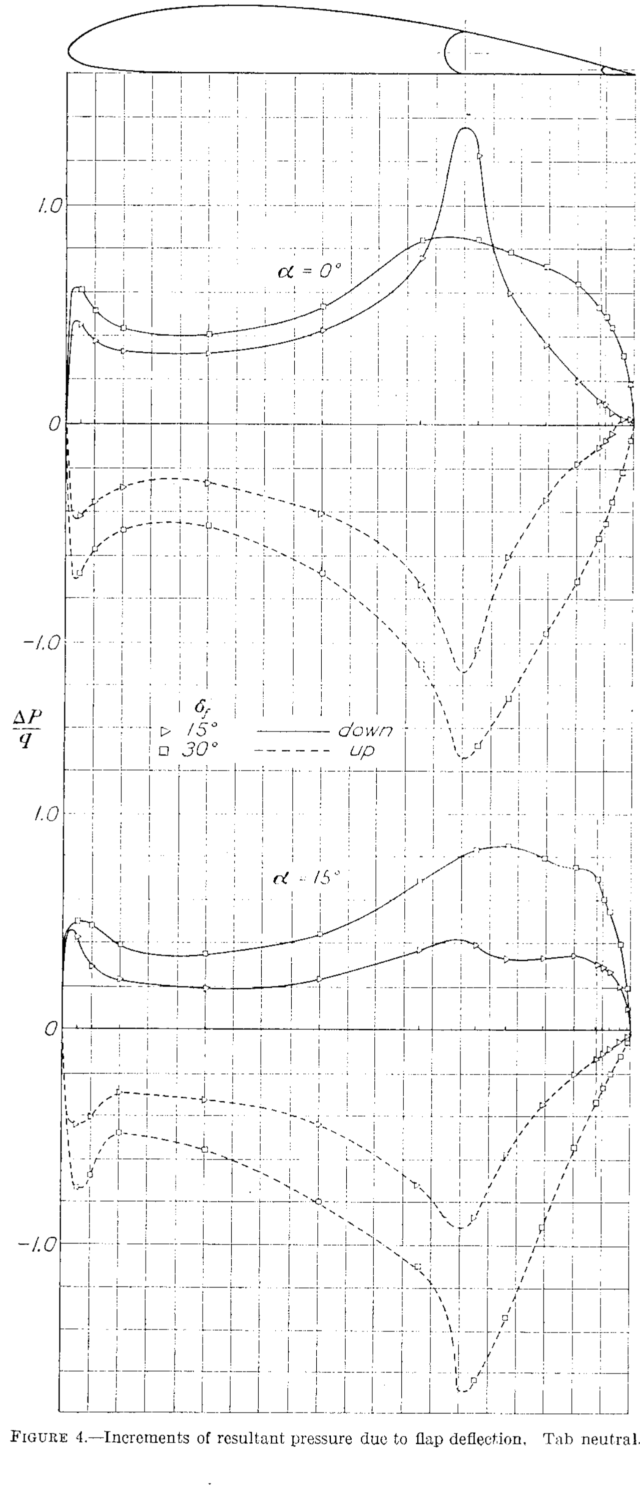

FIGURE 4.—Increments of resultant pressure due to flap deflection. Tab neutral.

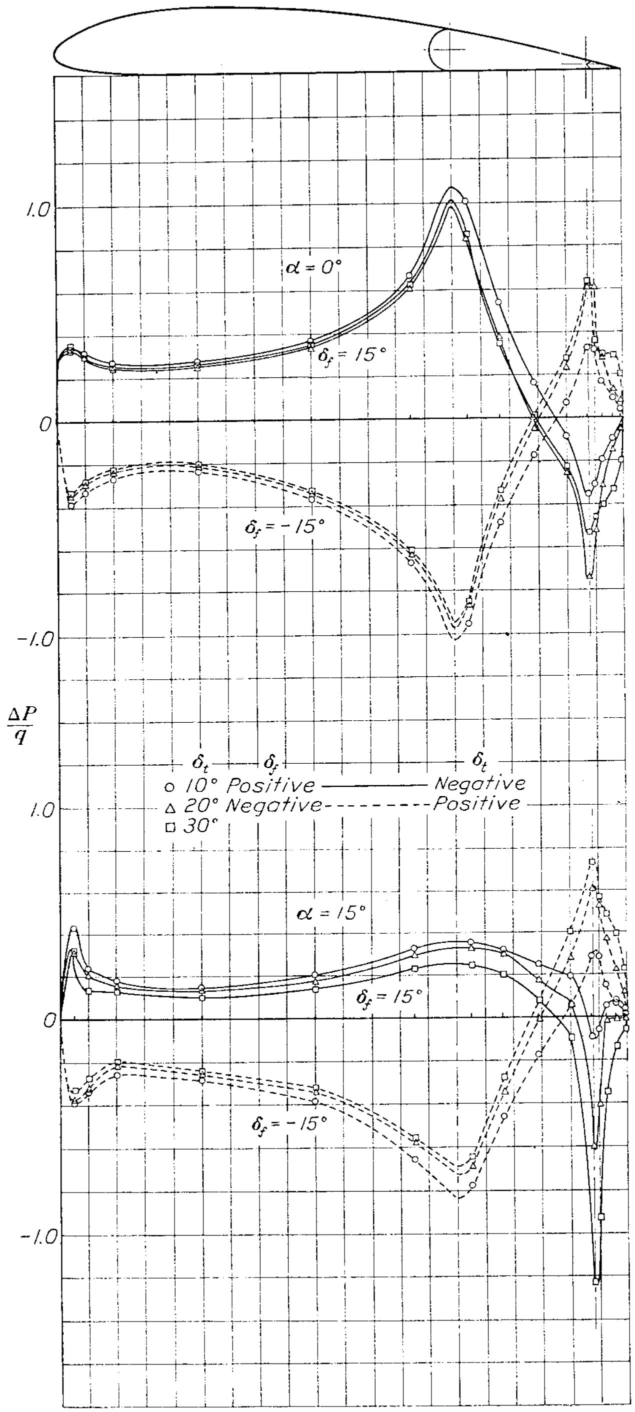

FIGURE 5.—Increments of resultant pressure due to combined tab and flap deflection. $\delta_f=\pm15°$.

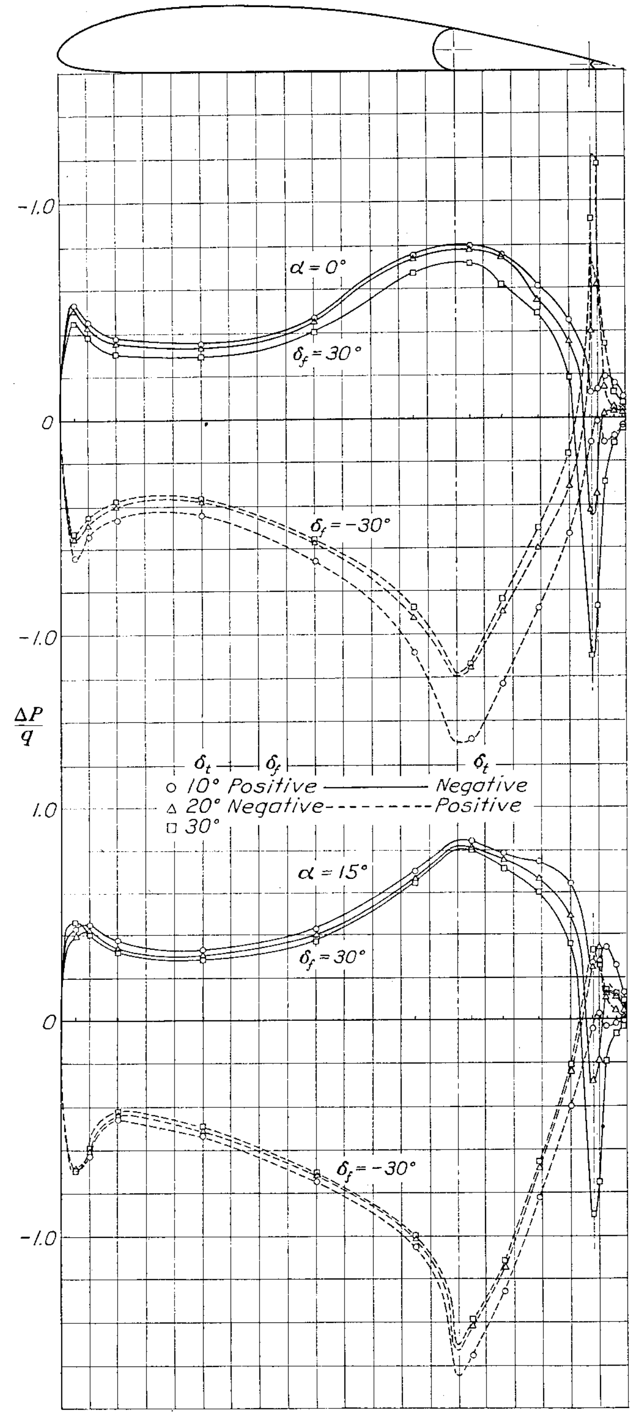

FIGURE 6.—Increments of resultant pressure due to combined tab and flap deflection. $\delta_f=\pm30°$.

deflections with given tab settings. With the tab deflected it will be noted that the curves are displaced parallel to the curve for the undeflected tab. This parallel nature of the curves shows that the variation of increments with flap deflection, considered with respect to any given initial tab deflection, is independent of tab deflection. At 30° deflection of the tab, however, the effectiveness of the tab appears to have been considerably reduced so that tab deflections of 20° should not be exceeded with the arrangements tested.

Increments to the basic values of flap section normal-force and hinge-moment coefficients are plotted in figure 9 for various flap deflections with given tab settings. The curves for the tab-deflected condition are displaced parallel to the curve for the undeflected tab, as was the case for the airfoil section increments. The variation of the flap increments with flap deflection for a given tab deflection are likewise independent of tab deflection.

Increments to the basic values of tab section normal-force and hinge-moment coefficients are given in figure 10 for various tab deflections with given flap settings. The curves for the flap-deflected condition are also displaced approximately parallel to the curve for the undeflected flap, over the range of tab deflections from $-20°$ to $20°$. The curves show that the variation of increments with tab deflection for a given flap deflection is practically independent of flap deflection.

Comparison with theory.—Theoretical expressions for the lift, pitching moment, and hinge moment for a thin airfoil with any multiply hinged flap system have been derived by Perring (reference 3). The following relationships apply to a thin airfoil with a flap and a tab, N. A. C. A. absolute coefficients being used:

Lift coefficient of airfoil:

$$C_L=\frac{dC_L}{d\alpha}\left(\alpha'+\frac{\partial\alpha}{\partial\delta_f}\delta_f+\frac{\partial\alpha}{\partial\delta_t}\delta_t\right) \tag{1}$$

Pitching-moment coefficient:

$$C_{m_{c/4}}=C_{m_0}+\frac{\partial C_m}{\partial\delta_f}\delta_f+\frac{\partial C_m}{\partial\delta_t}\delta_t \tag{2}$$

Hinge-moment coefficient of flap:

$$C_{h_f}=C_{h_{f_0}}+\frac{\partial C_{h_f}}{\partial C_L}C_L+\frac{\partial C_{h_f}}{\partial\delta_f}\delta_f+\frac{\partial C_{h_f}}{\partial\delta_t}\delta_t \tag{3}$$

Hinge-moment coefficient of tab:

$$C_{h_t}=C_{h_{t_0}}+\frac{\partial C_{h_t}}{\partial C_L}C_L+\frac{\partial C_{h_t}}{\partial\delta_f}\delta_f+\frac{\partial C_{h_t}}{\partial\delta_t}\delta_t \tag{4}$$

α' is the angle of attack of the main portion of the airfoil measured from zero lift of the undeformed section. (All angles are measured in radians.)

C_{m_0}, $C_{h_{f_0}}$, and $C_{h_{t_0}}$ are moment coefficients at zero lift of the undeformed airfoil.

Parameters $\frac{\partial\alpha}{\partial\delta_f}, \frac{\partial\alpha}{\partial\delta_t}, \frac{\partial C_m}{\partial\delta_f}, \frac{\partial C_m}{\partial\delta_t}, \frac{\partial C_{h_f}}{\partial C_L}, \frac{\partial C_{h_t}}{\partial C_L}, \frac{\partial C_{h_f}}{\partial\delta_f}, \frac{\partial C_{h_t}}{\partial\delta_t}$, are given in figure 11.

Parameters $\frac{\partial C_{h_f}}{\partial\delta_t}$ and $\frac{\partial C_{h_t}}{\partial\delta_f}$ are given in figure 12.

The curves given in figures 11 and 12 correspond to those given in reference 3 except that the values have been calculated and the curves redrawn on the basis of N. A. C. A. absolute coefficients.

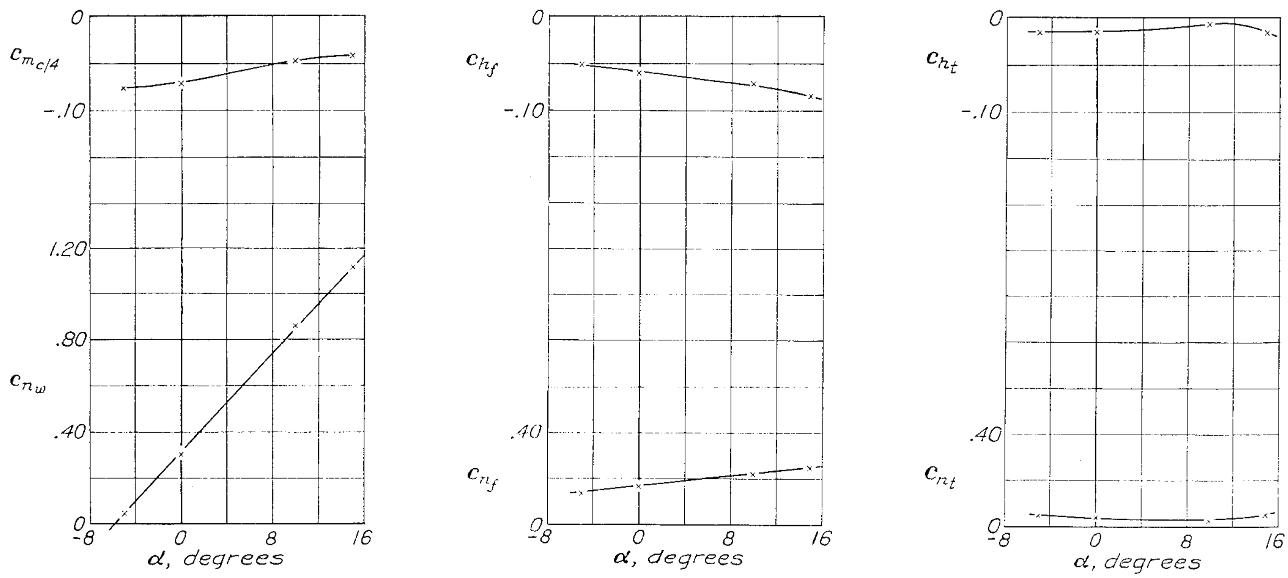

FIGURE 7.—Characteristics of the basic airfoil section. Tab and flap neutral.

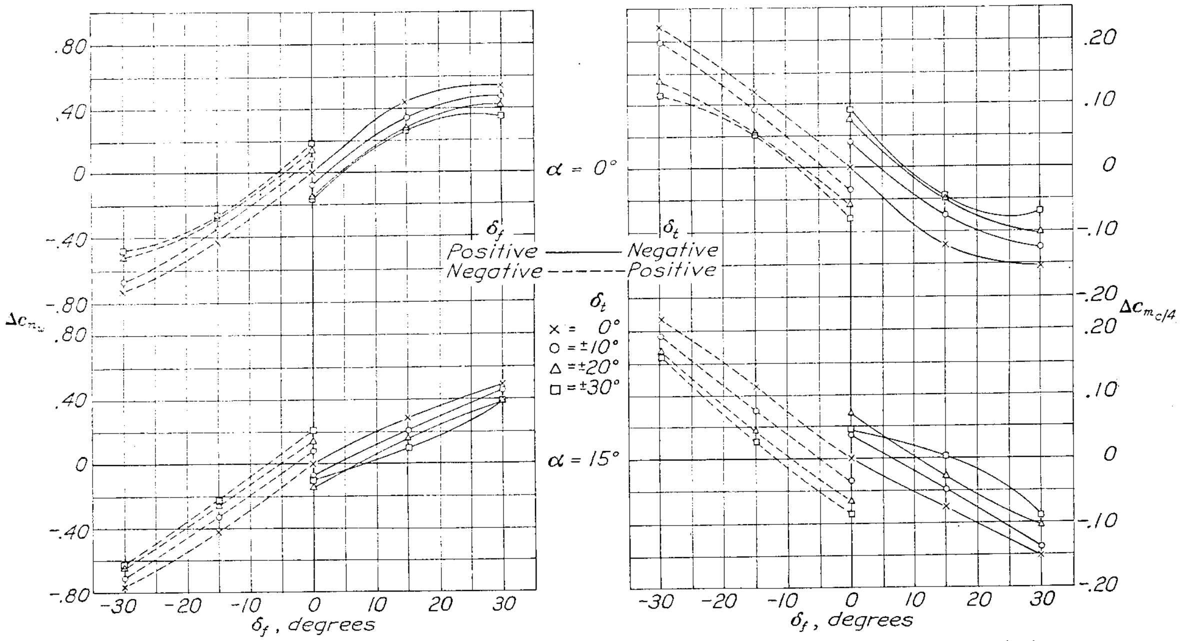

FIGURE 8.—Increments of airfoil section normal-force and pitching-moment coefficients for various tab and flap deflections.

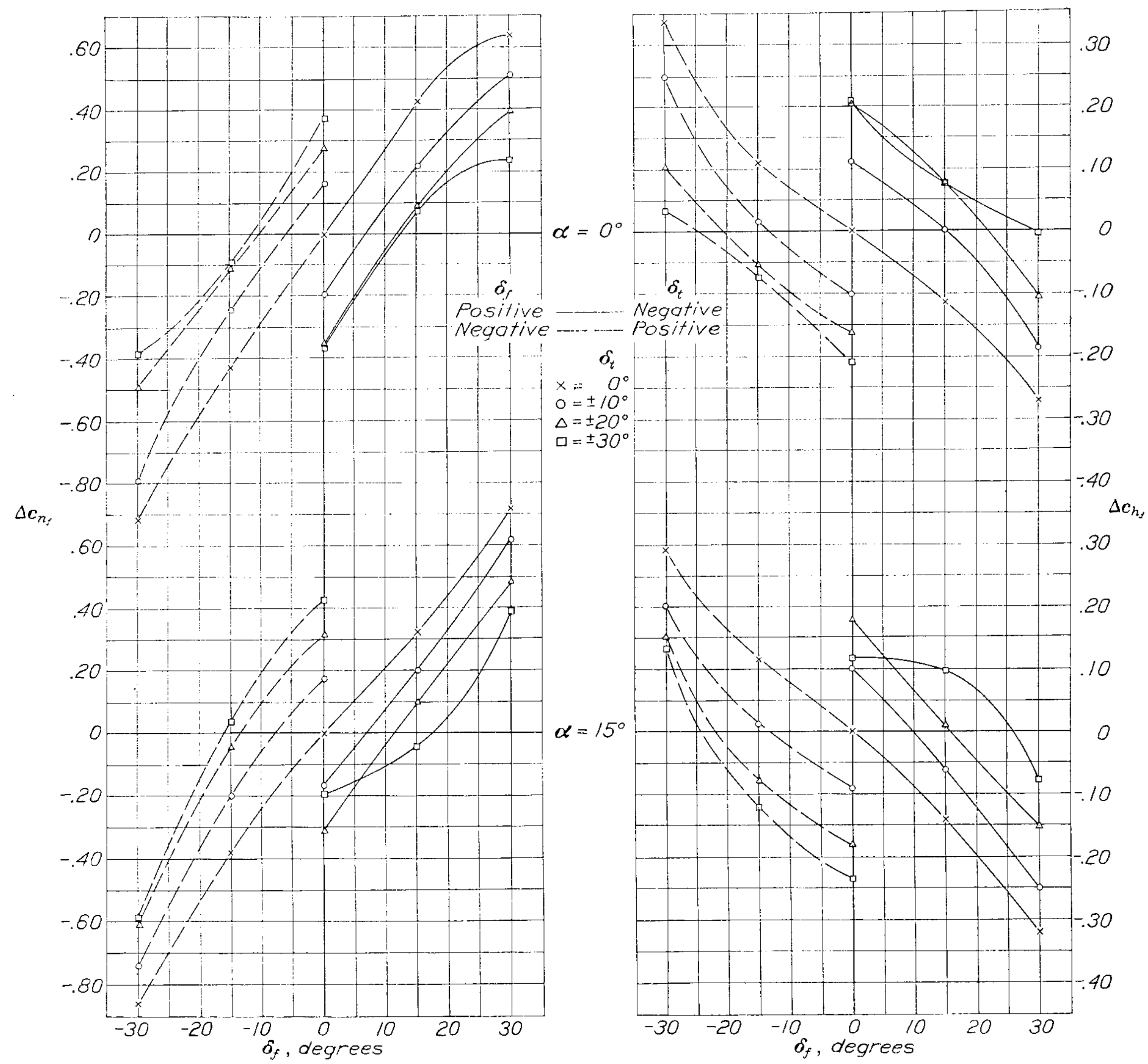

FIGURE 9.—Increments of flap normal-force and hinge-moment coefficients for various tab and flap deflections.

The theoretical and experimental values of airfoil section normal-force and pitching-moment coefficients are compared in figure 13. The data show that the theory agrees fairly well with experiment for flap deflections from 0° to ±15° with the tab neutral. Similar agreement was found in comparing data from reference 4 which deals with tests of a 30 percent chord flap. Reference 5 also shows good agreement of theory with experiment for small angular deflections with flaps 20 percent of the airfoil chord. With the tab and flap both deflected, however, the present investigation shows that the theory indicates considerably greater effects on the airfoil section normal-force and pitching-moment coefficients than are actually obtained by experiment.

Theoretical and experimental values of the flap hinge-moment coefficients are compared in figure 14. As in the case of the airfoil section coefficients, good agreement is shown between theory and experiment when the tab is neutral. With the tab deflected in a direction opposite to that of the flap, however, only one-half to two-thirds of the theoretical effect is obtained. Similar effects were shown by comparisons made in reference 6.

Values of the theoretical and experimental hinge-moment coefficients of the tab are compared in figure 15. This comparison shows a very poor agreement between theory and experiment, probably because of the small-chord tab (6 percent of the airfoil chord), which is operating in a somewhat turbulent region of air near the trailing edge of the airfoil and is therefore unable to produce its full effect.

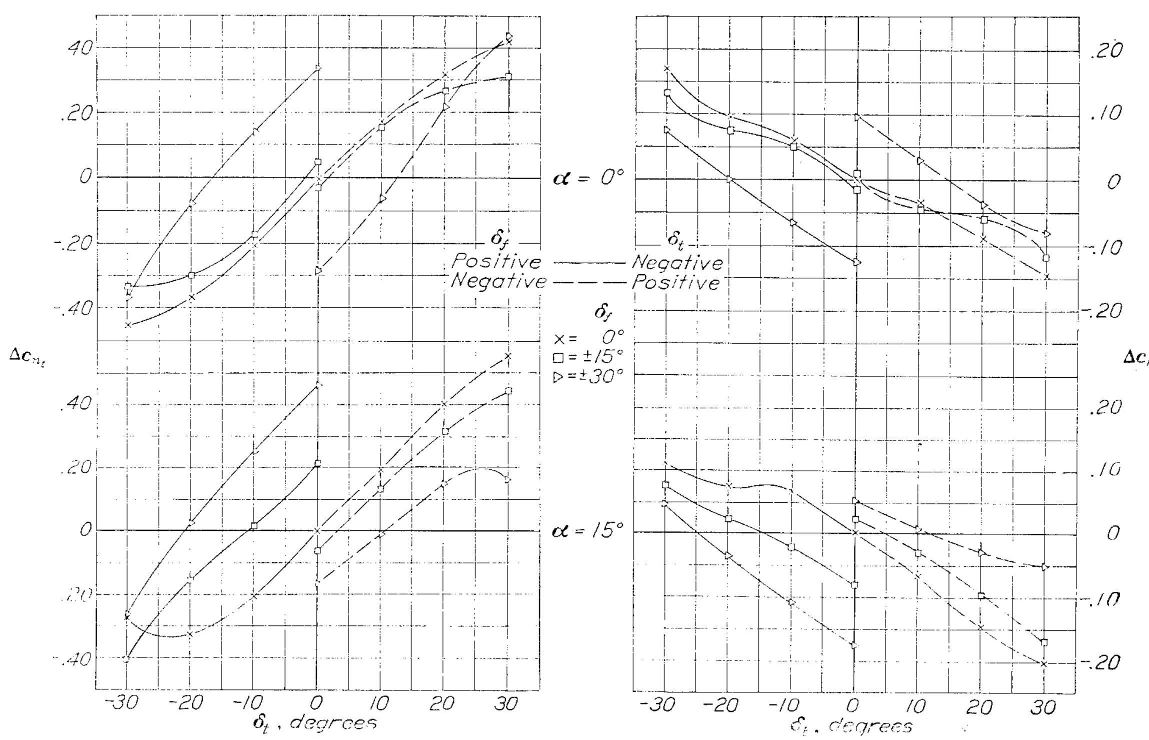

FIGURE 10.—Increments of tab normal-force and hinge-moment coefficients for various tab and flap deflections.

CONCLUSIONS

Based on the arrangement of airfoil section, flap, and tab tested, the following conclusions may be drawn:

1. Peak values of the increments of resultant pressures due to flap or to tab deflection occurred at the flap and tab hinges, respectively.

2. The variation of increments of airfoil section normal-force and pitching-moment coefficients and of flap normal-force and hinge-moment coefficients, due to flap deflection with a given tab setting, was practically independent of the tab deflection.

3. The variation of increments of tab normal-force and hinge-moment coefficients with tab deflection for a given flap setting was practically independent of flap deflection.

4. Comparisons of the theoretical with the experimental forces and moments for the airfoil section with flap and tab shows that the theory agrees fairly well with experiment for small flap deflections with the tab neutral, but that the theory indicates much greater effects than are actually obtained when the flap and tab are simultaneously deflected.

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Langley Field, Va., *December 10, 1935.*

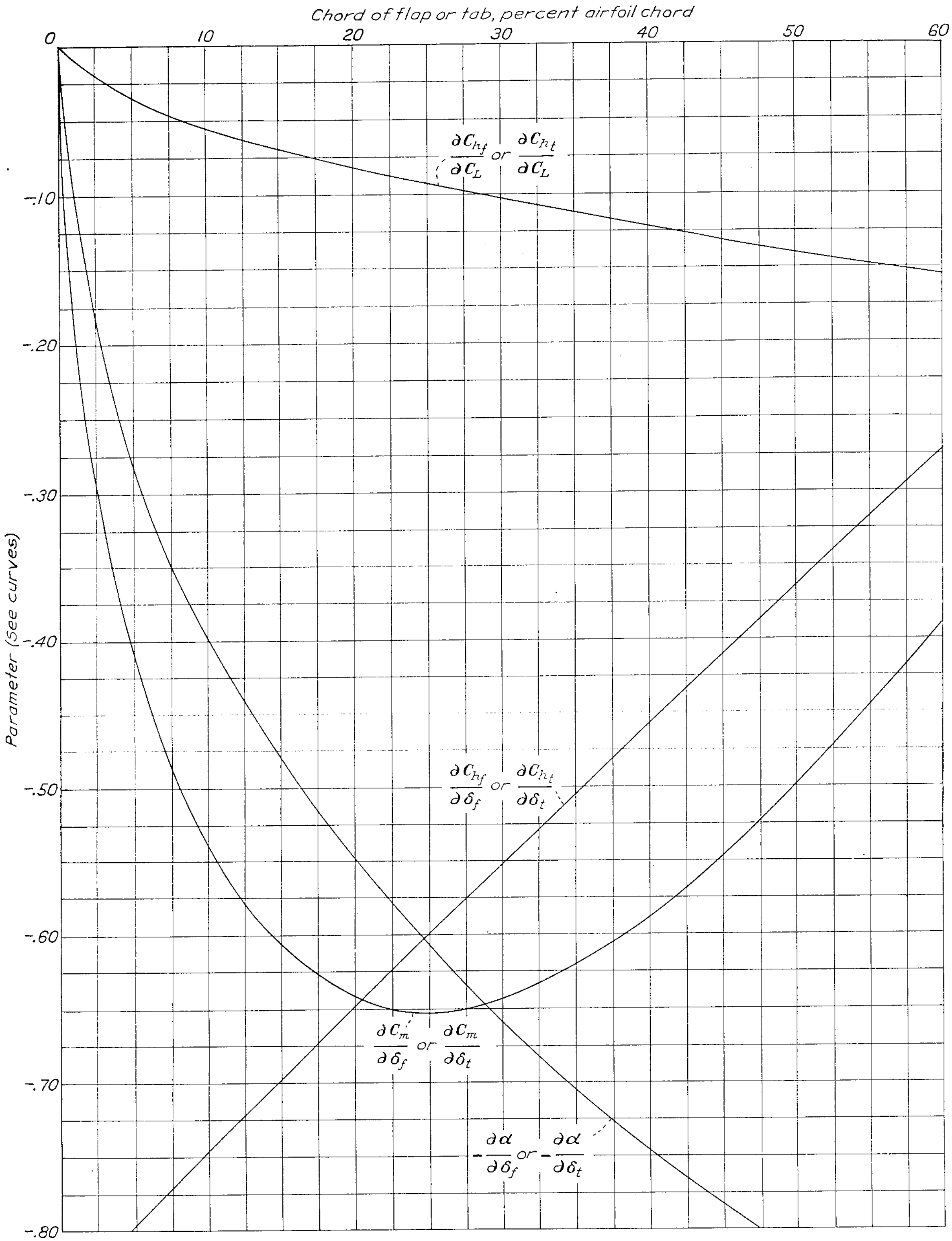

FIGURE 11.—Parameters for computing lift, pitching moment, and hinge moment.

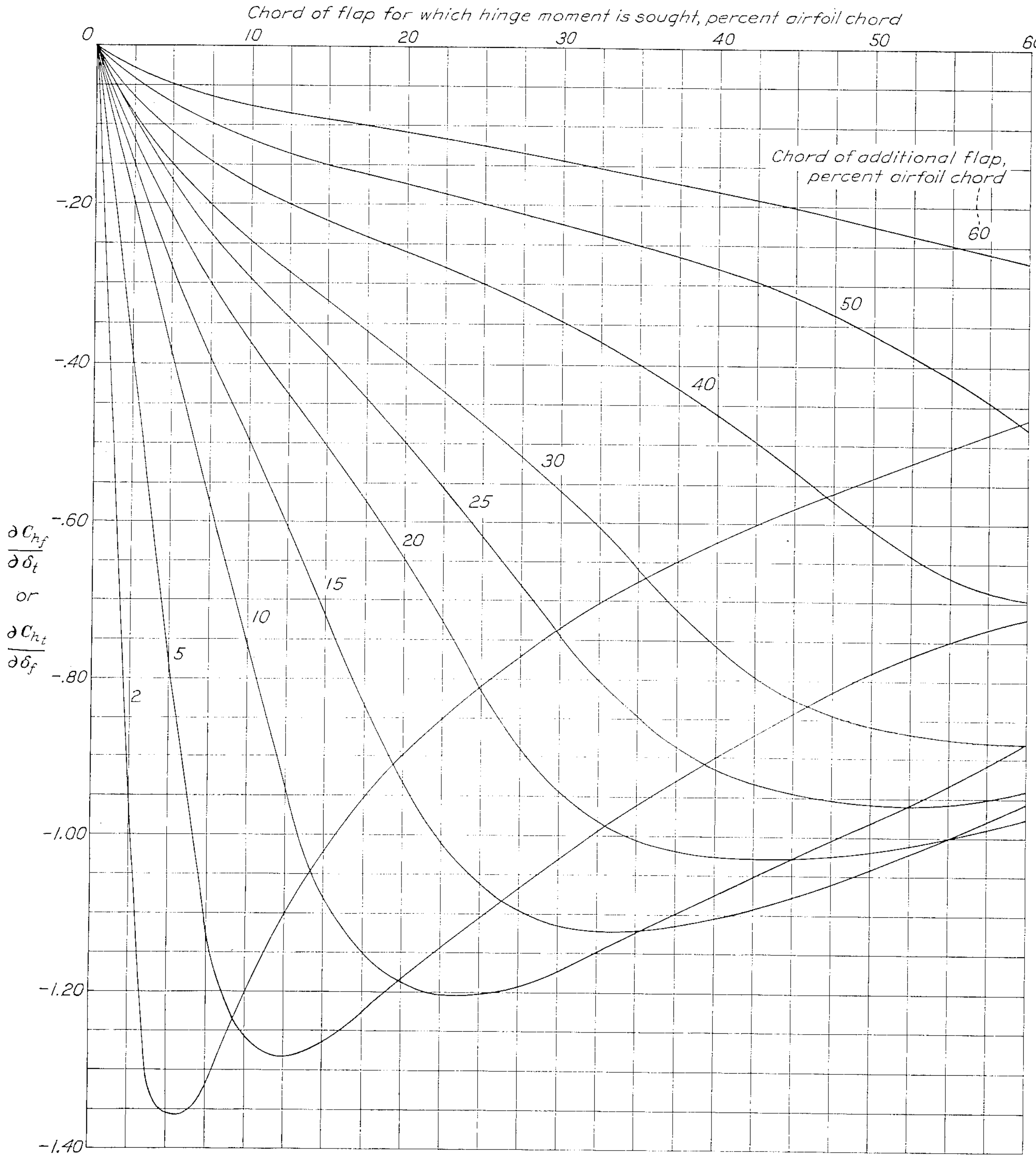

FIGURE 12.—Hinge-moment parameters. Increments in ratio of $\frac{\text{flap hinge moment}}{\text{tab angle}}$ or $\frac{\text{tab hinge moment}}{\text{flap angle}}$.

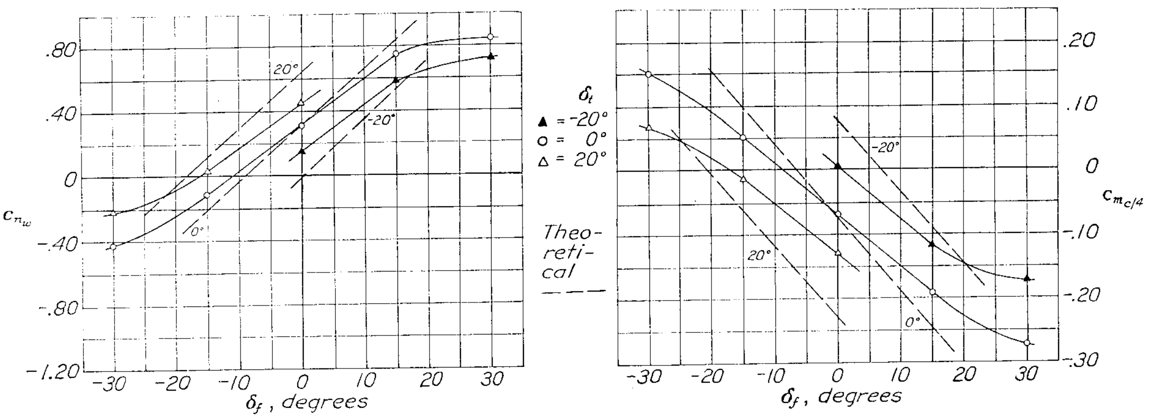

FIGURE 13.—Comparison of theoretical and experimental values of airfoil section normal-force and pitching-moment coefficients. Clark Y section with flap and tab. $\alpha=0°$

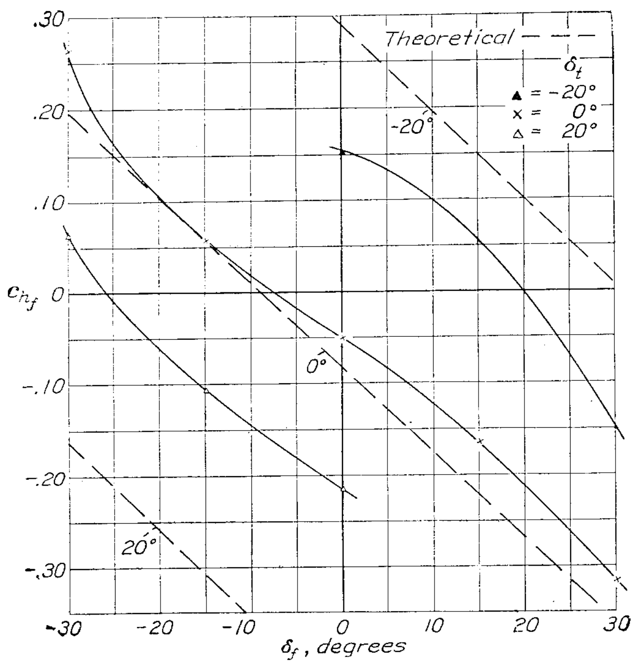

FIGURE 14.—Comparison of theoretical and experimental hinge-moment coefficients of flap with tab. Clark Y airfoil section. $C_L=0.3$.

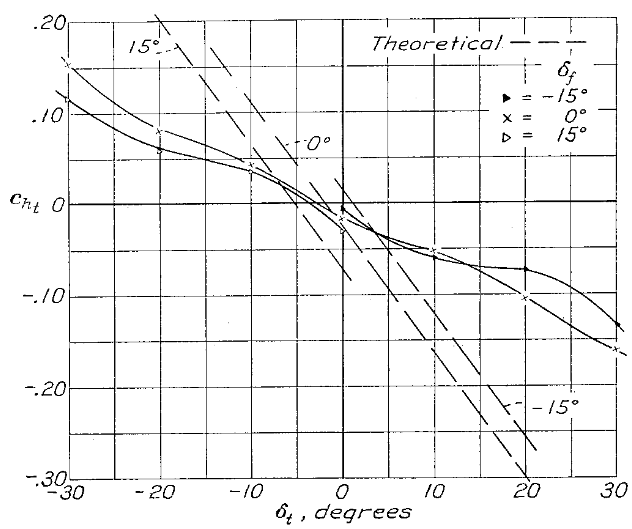

FIGURE 15.—Comparison of theoretical and experimental hinge-moment coefficients of tab. Clark Y airfoil section with flap and tab. $C_L=0.3$.

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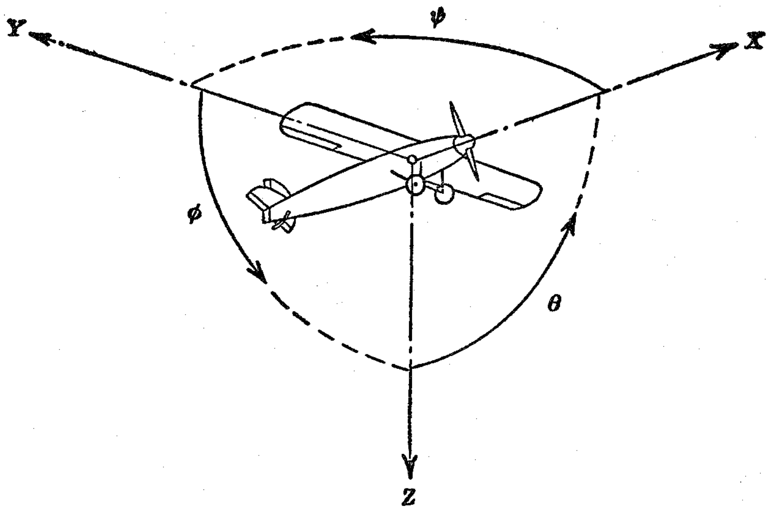
U. S. GOVERNMENT PRINTING OFFICE: 1936



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l=\frac{L}{qbS}$ (rolling) $C_m=\frac{M}{qcS}$ (pitching) $C_n=\frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter
p, Geometric pitch
p/D, Pitch ratio
V', Inflow velocity
V_s, Slipstream velocity
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2D^5}$

P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3D^5}$
C_s, Speed-power coefficient $=\sqrt[5]{\frac{\rho V^5}{Pn^2}}$
η, Efficiency
n, Revolutions per second, r.p.s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.
1 metric horsepower = 1.0132 hp.
1 m.p.h. = 0.4470 m.p.s.
1 m.p.s. = 2.2369 m.p.h

1 lb. = 0.4536 kg.
1 kg = 2.2046 lb.
1 mi. = 1,609.35 m = 5,280 ft.
1 m = 3.2808 ft.